

ORIGINAL ARTICLE

Residential and occupational exposure to 50 Hz magnetic fields and malignant melanoma: a population based study

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Aims: To test the hypothesis that exposure to electromagnetic fields from high voltage power lines increases the incidence of cutaneous malignant melanoma in adults aged 16 and above.

Methods: Nested case-control study. The study population comprised subjects aged 16 and above who had lived in a residence situated in a broad corridor around a high voltage power line in 1980, or one of the years from 1986 to 1996. The cases were incident cases that were diagnosed in 1980–96 and reported to the Cancer Registry of Norway. Two controls were matched to each case by year of birth, sex, municipality, and first year entering the cohort. Time weighted average exposure to residential magnetic fields generated by the power lines was calculated for the exposure follow up from 1 January 1967 until diagnosis by means of a computer program, in which distance from residency to the line, line configuration, and current load were taken into account. Exposure was analysed using cut off points at 0.05 and 0.2 microtesla (μ T). Exposure to magnetic fields at work was classified by an expert panel who assessed magnetic field exposure by combining branch and occupation into one of three levels: <4 hours, 4–24 hours, and >24 hours per week above background (0.1 μ T). The categories were cumulated over the occupationally active years for the exposure follow up from 1 January 1955 until diagnosis, and cut off points at 18 and 31 category-years were evaluated.

Results: Analysis of the two upper residential magnetic field categories showed an odds ratio of 2.01 (95% CI 1.09 to 3.69) and 2.68 (95% CI 1.43 to 5.04) for women, and an odds ratio of 1.70 (95% CI 0.96 to 3.01) and 1.37 (95% CI 0.77 to 2.44) for men, respectively. Occupational exposure showed no significant association with cutaneous malignant melanoma, and analysis of both residential and occupational exposure simultaneously, showed no additional effect.

Conclusion: The present study provides some support for an association between exposure to calculated residential magnetic fields and cutaneous malignant melanoma, but because of the lack of a biological hypothesis and the known strong association between solar radiation and melanoma, no firm conclusions can be drawn and further studies would be of interest.

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Solar ultraviolet radiation (UVR) is a well established risk factor for cutaneous malignant melanoma (CMM),¹ but many factors are still obscure. A recent report from Norway indicated that sun exposure at any age is of importance for the lifetime risk of CMM.² The study also showed that it was half as hazardous to be born in the northern part than in the southeastern part of Norway.

Since 1979, a large number of studies have reported increased cancer risk in children and adults exposed to extremely low frequency magnetic fields; of particular interest have been leukaemia, brain tumours, and more recently breast cancer. Recently, an International Agency for Research on Cancer (IARC) working group evaluated extremely low frequency (ELF) magnetic fields as possibly carcinogenic to humans, based on the statistical association of higher level residential magnetic fields and increased risk for childhood leukaemia.³ No consistent evidence was found for other cancer sites in children and adults in relation to such exposure.

Few studies have addressed CMM in relation to residential electromagnetic field exposure. A study from Finland reported a non-significant increased incidence rate ratio of melanoma in adults living close to power lines.⁴ Studies of workers in the telecommunications, electronics, and electric utility industries have reported increased risk of melanoma,^{5–8} but an alternate explanation for this finding has been exposure to polychlorinated biphenyls⁷; other studies addressing CMM and exposure to magnetic fields at work have yielded mixed results.^{9–13} A recent report linked uveal melanoma to a history of

employment in occupations involving use of selected radio frequency radiation transmitting devices.¹⁴ An increased risk of CMM has also been reported in airline crew, but although they are exposed to cosmic radiation and electromagnetic fields, the most likely explanation for the risk shown is increased exposure to solar radiation.¹⁵

The study of melanoma was a priori motivated by the hypothesis proposed by Stevens, in which electromagnetic fields may contribute to hormone related cancers.¹⁶ According to the hypothesis, reduced melatonin production in exposed individuals will be accompanied by an increase in oestrogen secretion by the ovary and prolactin secretion by the pituitary gland. Reports have indicated that melanoma cells have both melatonin and oestrogen receptors.^{17,18} Animal studies addressing the role of 50/60 Hz magnetic fields in carcinogenesis have indicated interactions between such exposure and melatonin, but the experimental evidence is still insufficient for any firm conclusions to be drawn, and results from animal and human studies investigating possible suppressing effects of ELF magnetic fields on melatonin have yielded equivocal results.^{3,19}

The aim of this study was to test the hypothesis that exposure to 50 Hz residential and occupational magnetic fields of

Abbreviations: CI, confidence interval; CMM, cutaneous malignant melanoma; ELF, extremely low frequency; GIS, geographical information systems; OR, odds ratio; TWA, time weighted average; UVR, ultraviolet radiation

the type generated by high voltage power lines increases the risk of CMM in relation to the subjects' calculated exposure to magnetic fields on the basis of data on line configuration and historical loads on power lines.

METHODS

Study population

The study population comprised all persons (aged 16 and above) who, at 1 November 1980, or at 1 January in at least one of the years from 1986 to 1996 had lived in a residency in a broad corridor around a high voltage power line. A person entered the cohort the first year he was registered in a residency within the corridor. The corridor around each power line was established through geographical information systems (GIS), and was chosen to be wide enough to ensure that it included both exposed and unexposed residences. The Norwegian Mapping Authority provided the coordinates of every Norwegian residence linked to its address, and the Norwegian Water Resources and Energy Directorate provided the coordinates of power lines from 33 to 420 kV. By combining this information, distance from residences to a power line was calculated within the corridor. With reference to the address code, Statistics Norway was able to identify individuals who had lived in such a residency at the above mentioned points in time.

Cases and controls

The cohort was linked to the Cancer Registry of Norway by using the unique identification number; we identified all persons diagnosed with melanoma between 1 January 1980 and 31 December 1996, aged 16 and above. For each case, two controls were selected at random from the cohort using the following criteria: alive at the time of diagnosis of the case and entering the cohort at the same year as the case, matched for sex, year of birth (± 5 years), and municipality at the first point in time entering the cohort. Subsequently, Statistics Norway provided a residential history for cases and controls as far back as 1967; for the years 1967 to 1985, migration within a municipality was not registered; from 1986 to 1996 migration within a municipality was registered. By combining this information with the start year for the power line, a subject's years in a home near a power line could be identified.

Cancer registration

The Cancer Registry has recorded all new cases of cancer in Norway since 1953.²⁰ The system is based on compulsory reporting by hospital departments and histopathological laboratories. The coding of cancers is based on a modified version of the International Classification of Diseases, 7th revision (ICD-7).

Exposure to magnetic fields

Residential exposure was defined as magnetic fields generated by power lines close to dwellings. The exposure follow up was from 1 January 1967 until year of diagnosis. The calculations were performed by use of a computer program (Teslaw) developed at SINTEF Energy, Norway. The program presents the result as μT root mean square magnetic field strength. This is the sum of the vectors for the individual conductor in a given situation integrated over one period. Underground cables were not taken into account because they are not believed to be a significant source of magnetic fields. The calculations took account of height of towers, distance between phases, ordering of phases, distance between the power line and the house, and average (mean) load on the power line for each year a study subject had lived in the house. Changes of the configuration of the power lines were taken into account. Based on the fact that GIS information was somewhat crude regarding distances to power lines, we decided to collect corrected distances from economic maps (scale 1:5000) for the residencies situated in the closest half of the corridor. Distance

to the power lines was defined as the distance from the closest corner of the house to the midpoint between the outer phases of a line. The historical load was estimated as the yearly average loads in amperes for each year the study subject had lived close to the line. The loads for one year were usually based on day to day records. If a record was not available, the historical load was assessed by experienced staff members of the power company on the basis of information for nearby lines and present and historical knowledge of the company's transmission and distribution system. Time weighted average (TWA) residential exposure to magnetic fields was a priori divided into three categories, with cut off points 0.05 and 0.2 μT . The first was based on the fact that Norwegian homes in general have low exposure,²¹ the latter on the cut off used in earlier reports in the literature. The following exposure parameters were evaluated: TWA from 1 January 1967 until diagnosis, and TWA for the five years before diagnosis.

Exposure to magnetic fields at work was assessed a priori, and the method was a practical modification of the method of expert judgement used by Flynn and colleagues.²² The assessment was individually performed by an expert panel and is described in more detail elsewhere.²³ A guideline, disseminated to the experts, was to assign a rank if they believed the job involved exposure above background level (0.1 μT): a rank of 1 if the level was less than four hours a week; a rank of 2 when more than four hours and less than 24 hours per week; and a rank of 3 if the job was above background level for more than 24 hours per week. The classification of a job was based on a 3–5 digit industry code and a 3 digit occupation code used at the Norwegian censuses in 1960, 1970, 1980, and 1990.^{24–25} For many subjects the 1990 occupation was missing; we therefore assigned the 1980 information to 1990. The exposure follow up was from 1 January 1955 until date of diagnosis, and the potentially occupationally active period was defined as the age interval 18–67. We cumulated exposure categories multiplied by the number of years. For subjects changing occupation between two censuses, we cumulated the first occupation until the midpoint between the two relevant censuses. We used the first and third quartile among the controls as cut off points. The values were 18 and 31 category-years, respectively.

Other factors

Educational level was used as indicator for socioeconomic status: 1, primary school; 2, secondary school; 3, university/

Table 1 Demographic information and distribution of TWA residential magnetic field exposure for cutaneous malignant melanoma cases and controls living close to high voltage power lines in Norway, 1980–96

Item of information	Cases	Controls
Total (n)	807	1614
Sex (%)		
Men	45.6	45.6
Women	54.4	54.4
Age (%)		
<40	25.5	25.5
40–49	19.8	19.8
50–59	17.4	17.4
60–69	17.0	17.0
70+	20.3	20.3
TWA residential magnetic fields (%)		
Men		
<0.05 μT	88.6	92.1
0.05–0.20 μT	6.0	3.7
≥ 0.20 μT	5.4	4.2
Women		
<0.05 μT	95.0	89.5
0.05–0.20 μT	2.7	5.0
≥ 0.20 μT	2.3	5.5

Table 2 Risk of cutaneous malignant melanoma by groups/subgroups of adults with magnetic field exposure living close to high voltage power line in Norway, 1980–96

Group/subgroup	Gender	<0.05 μ T*		0.05–0.20 μ T			≥ 0.20 μ T			p value†
		Cases (n)	OR	Cases (n)	OR	95% CI	Cases (n)	OR	95% CI	
TWA‡	Women	393	1.00	22	2.01	1.09 to 3.69	24	2.68	1.43 to 5.04	<0.001
	Men	326	1.00	22	1.70	0.96 to 3.01	20	1.37	0.77 to 2.44	0.103
	Both	719	1.00	44	1.85	1.22 to 2.81	44	1.87	1.23 to 2.83	<0.001
Latest five years§	Women	379	1.00	28	2.51	1.42 to 4.43	32	2.95	1.67 to 5.22	<0.001
	Men	308	1.00	28	3.44	1.84 to 6.42	32	1.66	1.03 to 2.68	0.002
	Both	687	1.00	56	2.91	1.92 to 4.43	64	2.10	1.46 to 3.02	<0.001

* μ T, microtesla.

†Test for trend by assigning the scores, 1, 2, and 3 to the three levels of exposure.

‡TWA, time weighted average from birth or 1 January 1967 until date of diagnosis for case.

§TWA for the latest five years before diagnosis.

Table 3 Risk of cutaneous malignant melanoma by part of body and exposure to calculated residential TWA* magnetic fields; adults living close to high voltage power line in Norway, 1980–96

Part of body	ICD-7 code	Gender	<0.05 μ T†		0.05–0.20 μ T			≥ 0.20 μ T			p value‡
			Cases (n)	OR	Cases (n)	OR	95% CI	OR	Cases (n)	95% CI	
Face, arm, leg	190.0–4, 6, 7	Women	258	1.00	17	2.19	1.08 to 4.43	16	2.78	1.28 to 6.05	0.002
		Men	124	1.00	7	1.15	0.45 to 2.86	11	1.49	0.68 to 3.27	0.267
		Both	382	1.00	24	1.74	0.99 to 3.01	27	1.92	1.21 to 3.59	0.002
Trunk	190.5	Women	120	1.00	4	1.16	0.32 to 4.22	8	2.94	0.95 to 9.10	0.068
		Men	187	1.00	14	2.24	1.03 to 4.86	8	1.02	0.48 to 2.87	0.200
		Both	307	1.00	18	1.88	0.97 to 3.64	16	1.67	0.84 to 3.24	0.003

*TWA, time weighted average from birth or 1 January 1967 until date of diagnosis for case.

† μ T, microtesla.

‡Test for trend by assigning the scores, 1, 2, and 3 to the three levels of exposure.

research degree. The information was collected from the census closest in time to the year of diagnosis with such information available. Type of residence allocated to the address positively identified as situated in the geographical area crossed by power lines for each individual in the study, was assigned as one family house or apartment. For some addresses the classification was not available. To evaluate the effect of magnetic field in two groups with anticipated different exposure to solar radiation, Norway was divided in two geographical regions: northern and northwestern part, and southern Norway, respectively, according to Robsahm and Tretli.² We also evaluated exposure by sex and by age above and below 55 years.

Statistical methods

The odds ratio (OR) was used as the measure of association between exposure and disease, and was computed by conditional logistic regression models for matched sets with the computer package EGRET.²⁶ The following potential confounders were evaluated in the model: educational level, type of building, and number of dwellings. Confidence intervals (CI) at the 95% level are given. A trend test for ordinal levels of exposure was performed by assigning the scores, 1, 2, and 3 to the three levels of exposure. To test whether there was a difference in effect for subgroups of sex, age, and geographical regions, we introduced an interaction term between total TWA magnetic fields and the variable defining the subgroup. A likelihood ratio test was performed.

RESULTS

Table 1 presents the demographic information and the TWA magnetic field exposure distribution for the 807 cases and 1614 controls.

Table 2 presents ORs for melanoma overall and by sex in relation to exposure to magnetic fields, given as total TWA and TWA during the latest five years. Since adjustment for educational level, number of dwellings, and type of residence did not affect the results, we only present the crude analysis. Both total analysis and analysis for women showed a significantly increased risk and an increasing trend both for overall TWA exposure to residential magnetic fields and for exposure during the latest five years. For men, a significantly increased risk and an increasing trend were seen only for TWA exposure during the latest five years. Analysis evaluating magnetic fields as a continuous variable yielded the following results for both genders combined: for overall TWA exposure, OR = 3.68 (95% CI 1.85 to 7.34); for exposure in the latest five years, OR = 1.88 (95% CI 1.33 to 2.66).

Based on our matching of sex, age, and geographical region, we evaluated a potential difference in effect over subgroups of these variables, and tested the difference by introducing an interaction term between total TWA magnetic fields and the variable defining the subgroup. Results of the likelihood ratio test were as follows: sex, $p = 0.05$; age above and below 55 years, $p = 0.85$; and two geographical regions, $p = 0.88$.

Table 3 presents risk of CMM with respect to part of body. CMM of the trunk showed a borderline increasing trend when both genders were analysed together. Face, arms and legs showed a significant increasing trend and a significant increased risk in the highest exposure category for both genders combined and for women alone.

Table 4 presents odds ratios for different levels of occupational magnetic field exposure. Results are presented for both genders as well as for women and men. The analysis yielded no increasing trend or any significantly increased ORs.

Analysis of subjects with exposure both at home and at work did not provide support for an additional effect of the

Table 4 Risk of cutaneous malignant melanoma in relation to occupational exposure to a magnetic field above background level (0.1 μ T); Norwegian adults 1980–96

Gender	<18*		18–30			≥ 31			p value†
	Cases (n)	OR	Cases (n)	OR	95% CI	Cases (n)	OR	95% CI	
Women	97	1.00	167	0.92	0.62 to 1.38	57	1.27	0.75 to 2.17	0.428
Men	40	1.00	152	1.47	0.75 to 2.94	145	1.48	0.72 to 3.05	0.489
Both	137	1.00	319	1.05	0.80 to 1.45	202	1.22	0.81 to 1.82	0.293

*Occupational exposure category \times years from 1 January 1955 until year of diagnosis. Category 1, <4 h/week; category 2, 4–24 h/week; category 3, >24 h/week.

†Test for trend by assigning the scores, 1, 2, and 3 to the three levels of exposure.

combined exposures (data not shown). Analysis of residential exposure ≥ 0.02 μ T only, and removing the highly exposed at work (category \times years = 18) gave the following results: for both genders combined, OR = 2.07 (95% CI 1.18 to 3.62, 29 cases); for women, OR = 2.83 (95% CI 1.25 to 6.39, 16 cases), and for men, OR = 1.71 (95% CI 0.74 to 3.93, 13 cases).

DISCUSSION

This study provides support for an association between residential exposure to magnetic fields and CMM, in particular for women. Occupational exposure showed no significant association with CMM, and analysis of both residential and occupational exposure simultaneously showed no additional effect.

The study was conducted within a well defined cohort, and selection bias was minimised by the use of data available at Statistics Norway. The study was not biased by differential recall of past exposure by cases and controls. We were successful in obtaining information pertinent to exposure estimation; all of the relevant data on power lines needed to calculate magnetic fields were available, and any misclassifications were probably non-differential. The urban-rural distribution of the residences and the high proportions of cases and controls from areas outside Oslo indicate that the analysis is based on a data set that represents different segments of the Norwegian population.

A previous dosimeter study among children living close to a power line in Norway showed that the magnetic fields from the line are the major source of exposure.²¹ This should also be the case for adults, in particular for those not exposed to magnetic fields at work. In comparison with other countries, such as Sweden, the contribution of ground currents to magnetic fields in homes is minor in Norway because of a different grounding system.

Based on the fact that moving within municipalities was available only for the period 1986 to 1996, study subjects with a history of moving (516 of 2421) have more reliable information on residential exposure if the moving took place in 1986 or later. No personal measurements of magnetic fields were available for the subjects included in our cancer study. This may be a weakness, but the findings of a Swedish study indicate that contemporary measured fields are inappropriate predictors of past fields of power lines.²⁷

Our finding of an increased risk of melanoma in relation to residential exposure does not have much support in the literature. A previous study from Finland showed an overall risk of 1.05 and 1.10 among men and women respectively, although no increasing trend was shown over four consecutive exposure levels.⁴ Risk of CMM has been reported to be increased in previous occupational studies. A Swedish study evaluating cancer incidence in relation to measured magnetic fields in various occupations showed an increased risk for melanoma, but no increasing risk over consecutive exposure categories.¹¹ A Norwegian study among workers in hydroelectric power companies showed an increased risk for melanoma in the highest magnetic field category,⁹ but other exposures, such as

polychlorinated biphenyls, could not be excluded as candidates for the demonstrated risk. A study from England was negative regarding CMM and electrical work¹³; other studies have shown mixed results.^{10–12}

The lack of association with occupational exposure in our study may be a result of the crude exposure classification or the low cut off point chosen for the exposure, therefore no firm conclusions can be drawn. The occupational exposure classification was only based on job titles and industrial branch. This approach may lead to misclassification, which may result in a reduction in the estimated odds ratios. The exposure classification method we used has previously been evaluated by Flynn and colleagues.²² They compared expert judgement with personal monitoring of exposure to magnetic fields and concluded that an expert panel was able to differentiate current job titles with regard to exposure to 50 Hz magnetic fields. Those job titles were, however, more detailed than the job titles used in this study. Occupational exposure in this study was defined by duration. Since the information on employment history was limited to four points in time represented by the four censuses, we also expect some misclassification of job titles, in particular for blue collar workers. Another explanation for the significant association only with residential and not with occupational magnetic field exposure may be related to the fact that exposure at night is more important, but this question is not possible to evaluate further using our data.

The biological mechanism for magnetic field effects is unknown. It has been suggested that electromagnetic fields act as tumour promoters rather than as initiators,¹⁹ especially as electromagnetic fields are not known to cause chromosomal damage.²⁸ Melatonin has been suggested to inhibit proliferation of CMM cells.²⁹ The fact that melanoma cells have melatonin receptors¹⁷ is interesting in light of the fact that electromagnetic fields have been suggested to reduce melatonin levels in electric utility workers,³⁰ but many negative studies have also appeared, and overall studies investigating possible suppressing effects of ELF magnetic fields on melatonin have yielded conflicting results.³

A possible explanation for the somewhat higher risk among women compared to men in our data may be related to the fact that women stay at home more than men, providing a more valid residential exposure estimate for women. Hormonal difference may also be of importance; however, melanoma cells do not express classical oestrogen receptors, although tamoxifen, an antioestrogen drug, has been shown to induce cell death in CMM.¹⁸

At present there is no strong reason to believe that magnetic fields cause malignant melanoma. The strong risk factor for CMM is solar UVR,¹ and our study has limitations in that individual data on UVR exposure were not available; confounding from this exposure may thus have occurred. Data from the national solar UVR monitoring network have shown that southern Norway receives about 50% higher UVR exposure per year compared with northern Norway.³¹ Our subanalysis by two regions addressing this gradient showed no significant difference in effect. Magnetic fields have been

Main messages

- The study found an increased risk of cutaneous malignant melanoma in adults exposed to residential magnetic fields from high voltage power lines. The risk was more pronounced for women.
- A possible biological mechanism behind the observed associations still needs to be determined.

Policy implications

- Our findings have no firm support in the scientific literature, and further research is needed.
- No firm conclusions can be drawn from this study based on the fact that solar radiation is a known strong risk factor for cutaneous malignant melanoma.

suggested to act as a co-promoter, although experimental data reported to date do not support this idea.¹⁹ One might speculate that our results may be a support to the suggested co-promoter effect of magnetic fields, but the idea is weakened by the lack of individual data on UVR exposure.

In the present population based, nested case-control study, we took advantage of the population registration system in Norway. Furthermore, by defining the study population as adults who had lived in geographical areas crossed by high voltage power lines, we could assume these lines to be the main source of exposure. The design made it possible to control for factors associated with area of residence, residential stability, and socioeconomic status. An association between CMM and magnetic fields cannot be rejected in our study, in particular not for women, but based on the small numbers involved, the many comparisons, the lack of a biological hypothesis, and the lack of support for this association in the literature, the results should be interpreted with caution. Exposure to UVR, a known strong risk factor for CMM, may still be a factor explaining or interacting with the risk shown, and further studies are necessary. Regarding occupational exposure the data are too crude to allow any conclusions to be drawn.

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